**Coated surfaces in static line contact: numerical simulation and experimental validation**

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***EXTENDED ABSTRACT***

Load bearing capacity (LBC) is becoming a demanding parameters for high strength components, especially in machine elements. Here, the request for high power density is continuously increasing due to the introduction of small powerful engines. As a consequence the severity of mating surface interaction grows, putting great demands on surface modification processes. Nevertheless, in such field trial and error approaches are still dominating with few experiences on numerical simulation are present.

The aim of this paper is to analyze the case of static line contact between two cylinders bodies, one of them being surface modified with mono and multilayered systems. Actually, line contact is representative of many bearing elements such as gears and rolling bearing components. Such case is studied by numerical modeling and validated by experimental tests aiming at analyzing failure behaviour of coated surface.

Actually, a FE Model developed for the analysis of failures of multi-layers coated surfaces subjected to the indentation is extended to the surface-damage analysis for the case of static line contact. This model featured with parameterized and cohesive-zone approach, allows for the propagation of cracks in the coating-layer being simulated, in parallel, critical load inducing the first crack under the varied situations being determined accurately and efficiently. The submodelling technique enable the scalling-down of geometrical model from macro-scale to micro-/nano-scale in order to study the fine cracks in the thin coating layer, the details modeling techniques can be referred from published paper[1].

The configuration studied for line contact is the so called ring-to-wheel (Fig.1). In the ring-to-wheel model, there is a significant difference in dimensions between two wheels (60 mm in diameter and 10 mm width for the large wheel and 24 mm in diameter and 5 mm in width for the ring) and coating thickness (2 μm), which makes difficult to establish a unified model to consider different length-scales. As mentioned before, to address this problem, a two-step analysis procedure is used: (1). Determine the contact condition (pressure and friction) in the contact area; and (2). Use a sub-model to represent the contact region in which the micron-scale coating is considered, as well as incorporation of cohesive elements for the prediction of the damage development. The FE model developed in this study was validated through a series of compression tests in the ring-to-wheel configuration. In such test different levels of loads were applied on the modified surfaces, being the critical load experimental definition given by the load at which surface cracks nucleate. Cracks were detected with scanning electron microscopy observations.

The studied surface modified systems are CrN, TiN and TiN/CrN nano-multilayer coatings applied on 42CrMo4 steel substrates. Part of the steel substrates was previous to coating subjected to active-screen plasma nitriding, whereas the other part was in simple quenched and tempered state. Coating deposition was performed with an industrial Cathodic Arc Evaporation PVD system.

Mechanical behaviour of the contact region of ring, represented by the sub-model loaded by the contact pressure and friction force, is investigated. The FE model for ring-to-wheel and the FE sub-model representing the contact region of ring are shown in Fig.1-2. The parabolic distribution of contact pressure and uniform surface shear force acts on the surface of ring. As it is done with multilayered system loaded by the indenter, the mechanical behaviour of sub-model of contact region of ring is also simulated with a variety of combination of coatings on either treated or untreated substrate steel. An example of the model and simulation results is shown in Fig. 3. The critical loads for the initiation of plastic deformation and the first crack based on the sub-model are shown in Table 1 and Fig.4-5. As is observed in the simulation for indentation test [2], for all configurations, when the ring is pressed against the wheel, the

crack occurs at the contact edge of coating surface of ring due to the tensile stresses caused by the plastic deformation of substrate. The highest load bearing capacity is observed for nano-multilayer structure of the coating TiN/CrN on the nitrided 42CrMo4. The critical load predicted is also compared with the test results and the comparison shows reasonable agreement (Fig. 6). Finally, figure 7 shows some SEM images of the surfaces of different coated systems subjected to a static compression test in the ring-to-wheel configuration, so as to have an actual comparison between the simulation and experimental results.

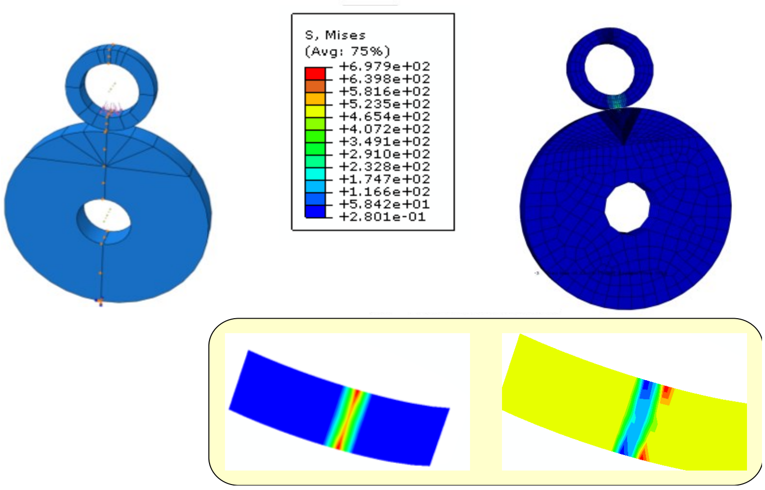


Figure 1. The ring-to-wheel structure and the contact pressure and surface stresses in the contact region of ring

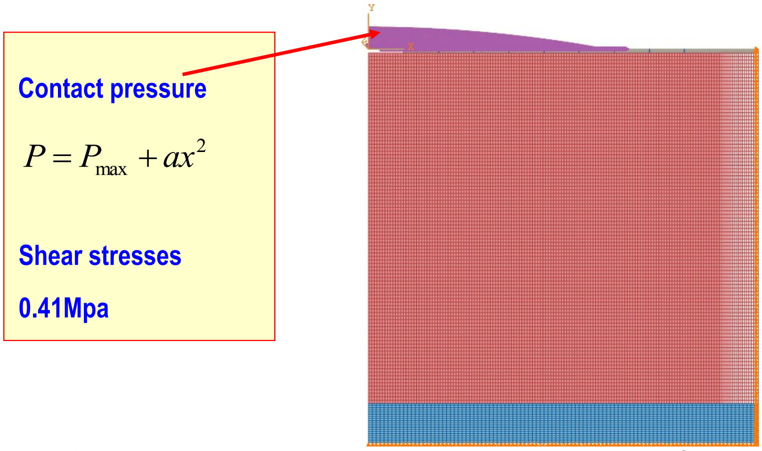


Figure 1 The sub-model representing the contact region of ring surface

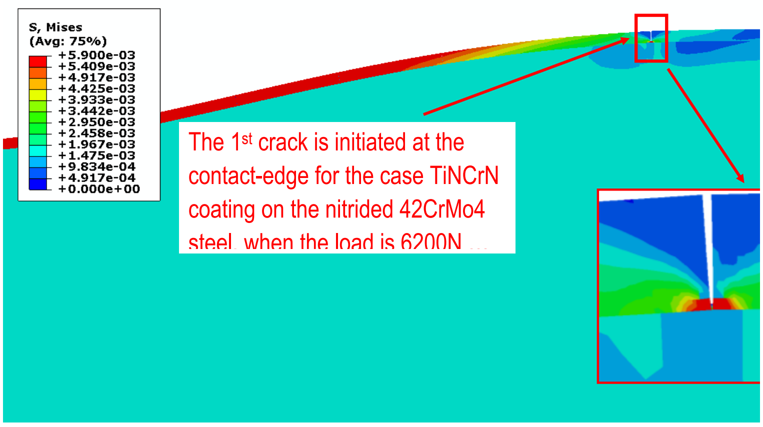

Figure 2 The critical load for ring-to-wheel constructure for the case TiNCrN on 42CrMo4 Nitrided

Table 1. Load bearing capacity for ring-to-wheel structure

| Substrate / Coating | Damage | | 42CrMo4 Non-Nitrided 42CrMo4 | 42CrMo4 Nitrided 42CrMo4 |
|---|---|---|---|---|
| TiN | Yield | Critical Load (N) | 677 | 740 |
| | | Peak of contact pressure (MPa),Pmax | 887.2 | 962 |
| | | Location | A | A |
| | | PEEQ | 0.0015 | 0.0059 |
| | Damage/Crack | Critical Load (N) | 3940 | 5700 |
| | | Peak of contact Pressure (MPa), Pmax | 5157 | 7410 |
| | | Location | B,C | B |
| CrN | Yield | Critical Load (N) | 300 | 580 |
| | | Peak of contact pressure (MPa) | 392 | 759 |
| | | Location | A | A |
| | | PEEQ | 0.00213 | 0.0018 |
| | Damage/crack | Critical Load (N) | 850 | 3200 |
| | | Peak of contact pressure (MPa) | 1112 | 4188 |
| | | Location | B | B |
| TiN/CrN | Yield | Critical Load (N) | 780 | 1000 |
| | | Peak of contact pressure (MPa) | 1014 | 1100 |
| | | Location | A | A |
| | | PEEQ | 0.0044 | 0.0014 |
| | Damage/Crack | Critical Load (N) | 4020 | 6210 |
| | | Peak of contact pressure (MPa) | 5262 | 8073 |
| | | Location | B,C,D | B |

A: Plastic deformation occurs in the substrate first; B: Crack occurs in the surface of coating; C: Crack occurs in the interface; D: Crack occurs between the interface and surface

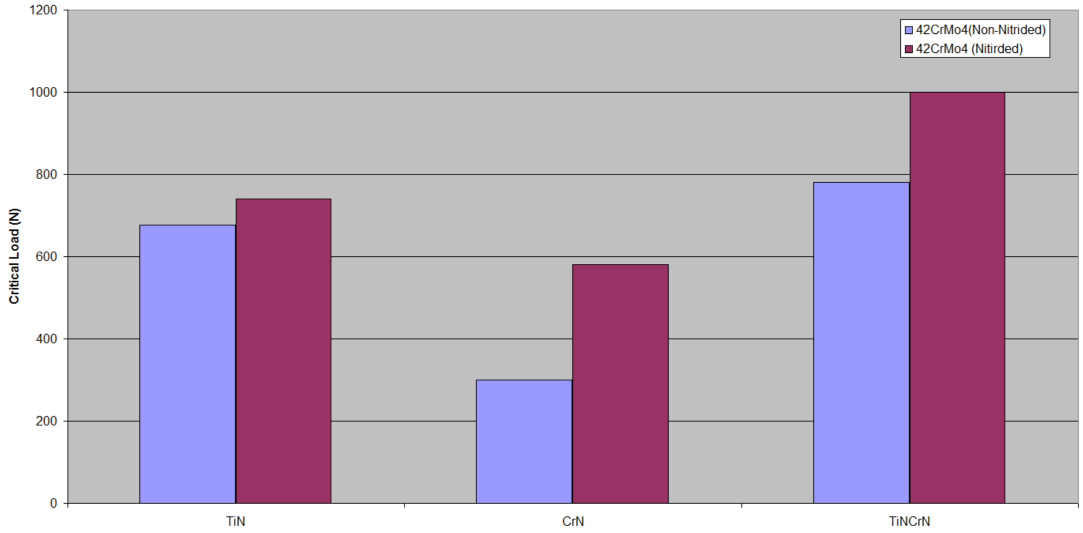


Figure 3 Critical Load in terms of the Initiation of Yield for Ring-to-Wheel Structure

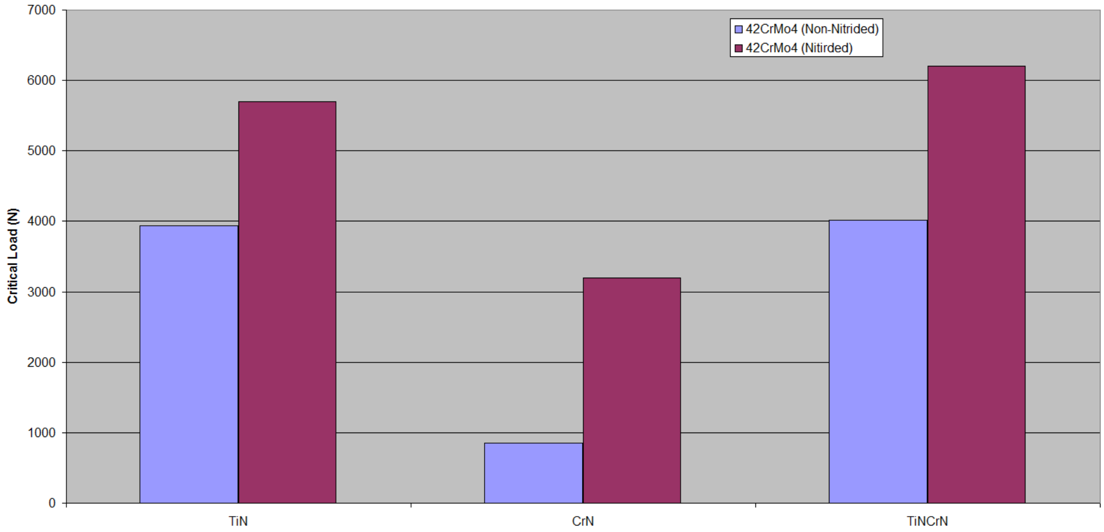


Figure 5. Critical Load in terms of the First Crack for Ring-to-Wheel Structure

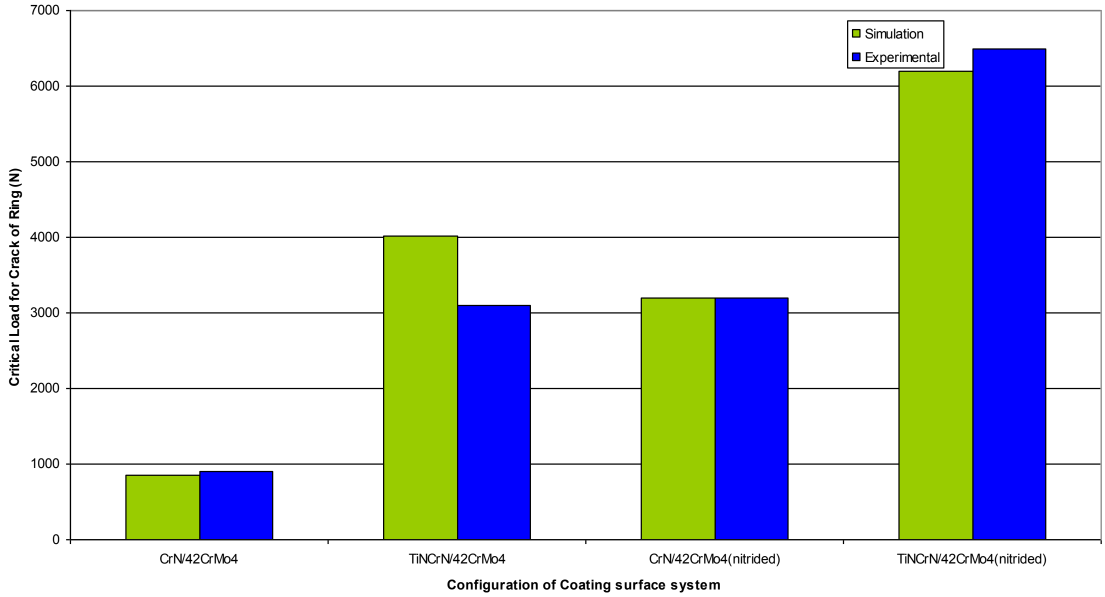


Figure 4 Comparison of Simulation and Experimental Results for Ring-to-Wheel Structure

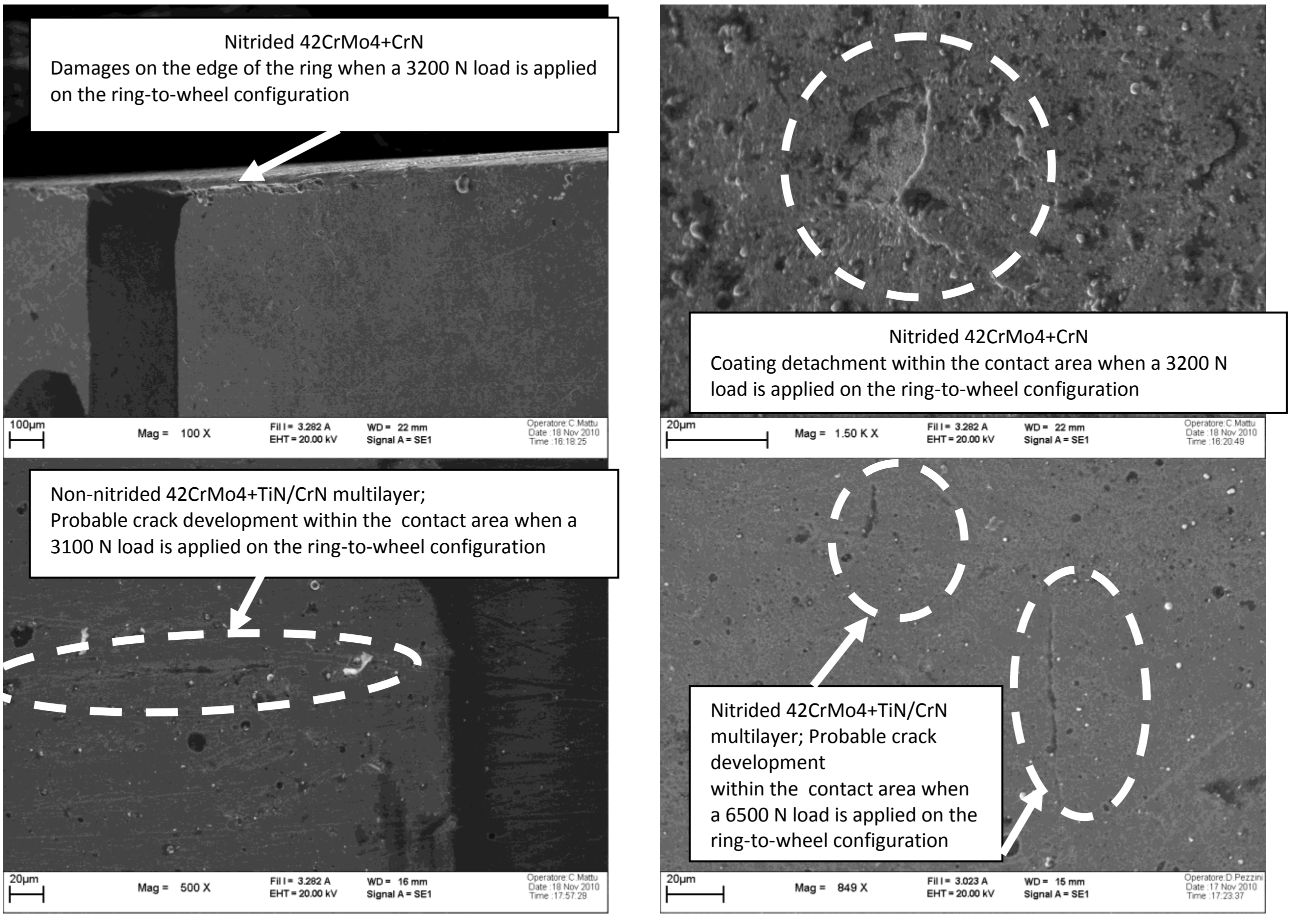


Figure 7. SEM Images of the edge or the contact area of different coated systems subjected to the static compression test in the ring-to wheel configuration.

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**Conclusions**
The main achievements of the research are:
(1) the CrN/TiN nano-multilayer coating outperformed the monolayer TiN or CrN coating;
(2) duplex treatment combining plasma nitriding with PVD coating possesses a much higher LBC than single coating;
(3) good agreement between modelling and experimental results has been achieved.

**Reference**
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2. Feng, J., Qin, Y, , Raghavan, R., Michler, J, Proc. of the ICTP 2011, pp. 1259-1264.